DEVELOPMENT IN WEAR DEBRIS MORPHOLOGICAL ANALYSIS AT RAF EARLY FAILURE DETECTION CENTRES

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Abstract: The RAF's Early Failure Detection Centres (EFDC) carry out routine inspection and analysis of magnetic drain plug samples taken from aircraft while in service. The captured debris is assessed in which morphological analysis is an important integral activity. The development of computerised procedures to identify and categorise the debris has led to the implementation at specific EFDC's of new, improved methods for detecting and diagnosing the wear condition of critical components. In this paper, the background to the development and application of these procedures is described in which the scope for predicting the future course of the wear and the prospects of introducing automatic analysis procedures are discussed.

Key Words: Computerised Procedures; Morphological Analysis; Wear Debris

Debris Analysis at RAF EFDC's: The RAF's Early Failure Detection Centres (EFDC) carry out routine inspection and analysis of samples taken from aircraft while in service. Magnetic Drain Plugs (MDP) are removed from aircraft for analysis in which the appearance of the captured debris is assessed and related to the wear condition of critical components. Techniques have been developed at Swansea for analysing particle morphology using computerised image processing and analysing methods to obtain detailed information about the wear condition of critical rubbing parts.

Figure 1 shows a schematic outline of the present scope for performing early failure detection and the current techniques in use at an EFDC. Clearly, a number of different monitoring technique are employed in various combinations to effect the most appropriate information for a wide range of operational conditions and aircraft types (1-2). Not all the techniques shown are utilised in every instance. However, the use of MDP units is common to all categories and this necessitates that the quantity of debris captured by a plug is measured (3-4). This is presently undertaken using the Debris Tester wear monitoring unit (5) which is then logged against 'Operating Hours'. Specific criteria are sometimes used to determine whether to recommend that the system being

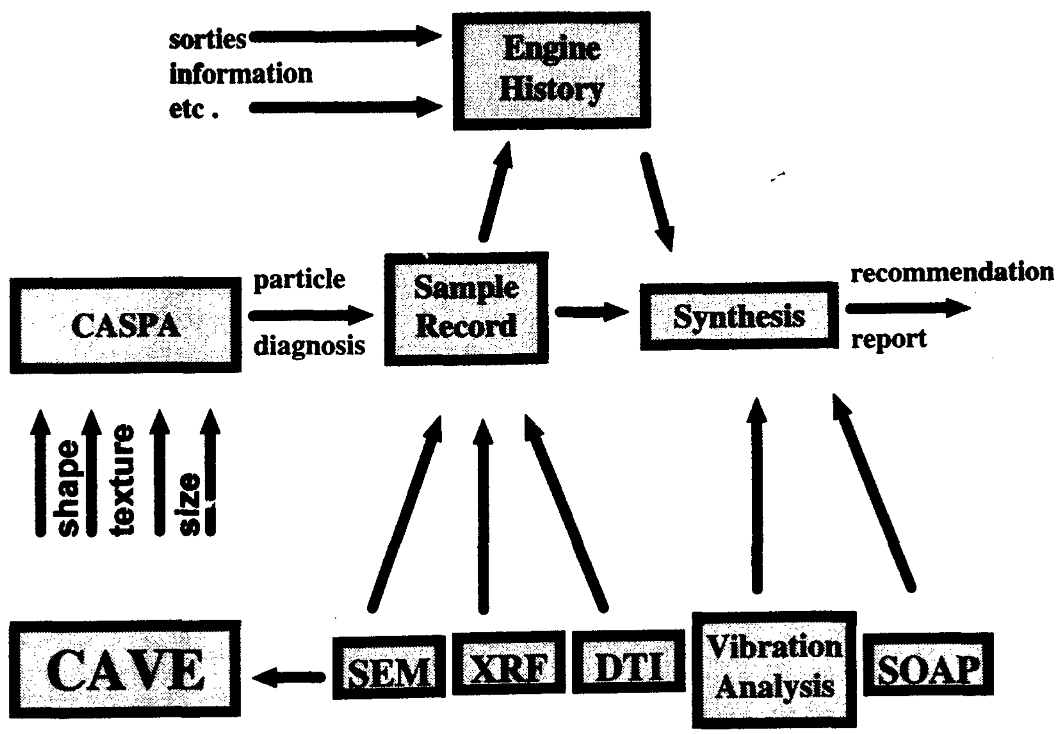

Figure 1 **The Integration of Wear Debris Analysis with Oil and Other Analyses and Data at RAF Early Failure Detection Centre**

monitored warrants closer inspection, or more frequent sampling, or even tha. it be immediately withdrawn from service. In most instances, where, based on the criteria, follow-up action is to be recommended, there is also a requirement that the debris be visually inspected and analysed to determine its morphological characteristics as a means of determining more precisely the source and type of wear occurring.

This is either undertaken by inspecting the debris directly on the plug itself, (large debris, typically of the order of a mm in linear dimension) or more usually, by placing a plug 'wipe' under an optical microscope and viewing it at a specific magnification, typically X50 overall magnification. Guidelines are provided to aid particle identification, but these are not universally applicable to every EFDC situation and are currently in the process of undergoing revision by the RAF.

The need to develop computer-aided procedures to assist in the identification of wear debris and performing reliable diagnosis has come to the fore in recent years because of the increasing complexity of modern machinery and the increased turnover of staff in many organisations. This often means that there is insufficient time available to develop the skills required to carry out this type of analysis to the level demanded in a highly specialised area involving a subjective type of activity. Consequently, this had led increasingly to the need to introduce procedures which assist in formalising the decision-making processes in order to provide systematic, and thus more objective, ways to perform the analytical tasks. This is something for which computers are ideally suited and is the basis of the developments at Swansea (6-7).

The main task in hand has been to adapt the original programs, (which are relevant to oil sampling and associated ferrographic wear particle analysis) to the needs of the EFDC methods of working. This is with particular reference to the different terminology used to describe magnetic drain plug debris and also, the fact that widely differing procedures and requirements are involved.

The purpose of this paper is to describe the background and procedures developed which has led to their implementation at EFDC's and to discuss the implications of the need to predict the future course of the wear in an engine once it has been detected and diagnosed. The scope for introducing automatic procedures for performing morphological analysis of debris is discussed.

Wear Debris Analysis: Debris transported from the wear site by the lubricant carry with them important information about the condition of the wear state of critical components in the machinery. The first, and most important information concerns the quantity of debris generated as a function (usually) of operating hours. It provides an excellent opportunity to 'trend' monitor the extent of the wear and the rate at which it is progressing. It also has the advantage that the debris quantity, or concentration, is quantitative and can usually be obtained quickly, simply and cheaply (5).

The RAF currently use the Debris Tester for this purpose (5) in which the debris concentration is plotted on a basis of wear debris concentration count per unit time versus operating (flying) hours. Based on experience, threshhold limits are preset for each engine type which permit further action to be taken when the limits are exceeded. The technique is thus used as a 'front-line tool' to detect the onset of active wear in a potentially deteriorating component wear situation.

Whereas most of the debris generated by the wear processes involved will be ferrous free metal, for certain aircraft types, e.g. the Tornado, it is important also to establish the composition of some of the non-ferrous debris generated so that a distinction can be made between 'active' and 'benign' wear. X-ray Fluorescence (EDXRF) and also, Scanning Electron Microscope (SEM) techniques are utilised for this purpose, as and when necessary.

Morphological analysis requires that the debris be viewed through a microscope (optical mainly, but sometimes scanning electron). The particular features, or attributes of interest are: size, (plain dimension and also the thickness), outline shape and edge detail, surface features and colour. The type of analysis usually employed is generally time-consuming, often tedious and invariably subjective. However, it is essential to carry out this type of analysis if we are to properly determine the type and cause of the wear and also clarify its severity .

The methods devised to perform morphological analysis are several and highly variable, although there have been attempts made to specify good practise which utilise either a wear particle atlas, (8) or attempt to lay down a set of rules for performing the analysis (0). There are now considerable opportunities available to exploit modern computerised procedures in association with artificial intelligence techniques, including the use of neural nets and image processing and analysis (10).

To adapt and apply these methods to the analysis of MDP samples, two separate, though related procedures have been developed in parallel, as follows:

- Wear Particle Analysis
- Computer-Aided Analysis of Morphology

Figure 2 indicates schematically the processes involved and how they interface with one another. In devising procedures for ultimate use at EFDC's, the following points must be borne in mind:

- the procedures devised must be clearly defined, easy to follow and quickly executed
- they must be compatible with other facilities and procedures already in operation at an EFDC
- they must be helpful and reliable in assisting personnel arrive at a correct diagnosis of the problem.

Application to EFDC Operations:

Wear Particle Atlas: The purpose of developing a series of annotated images is two-fold: it provides a reference document for debris associated with specific engine types which can be accessed by operators in the course of performing routine analyses of samples. It can also be used for tutorial sessions during training of inexperienced personnel.

The process used in the development was Hyper Text Mark up Language (HTML) to generate hyper-linked text and images comprising scaled images of debris, galleries of 'thumbnail' images with explanations of components and other relevant information, (including engine history, drawings of key components, etc.).

This method of displaying information permits the operator to switch rapidly from one source of information to another and is entirely 'mouse-operated'. Up-dates on information or images can be inserted easily with appropriate commentary to aid future analysis. Electronic transmission, e.g., from one EFDC to another, is easily effected either through normal (telephone) communication channels, or 'secure' channels if preferred.

The principal advantage of using this method is that the atlas can be specifically dedicated to the requirements of a particular engine type or EFDC operation, and the scope for building a 'library' of particle images is unlimited without the need to generate 'paper' records.

Figure 3 shows a sample 'page' extracted from the atlas.

Computer-Aided Morphological Analysis: The purpose in utilising a computer-aided system for analysing particle morphology is to establish a systematic procedure to arrive at a reliable identification of a specific particle which is linked to a capability to document the information and prepare a report defining the results of the overall analysis of the sample. When linked to other information about the sample it should also be possible to formulate an accurate diagnosis of the wear condition and associated fault in the system.

The present development is an extension of a previous program, CASPA (Computer-Aided Systematic Particle Analysis) which was established to assist in the analysis of wear debris extracted from oil samples using the ferrography method (6). The new version is based on the original version but is dedicated to the analysis of magnetic drain plug debris and is configured in 'Windows' format. It can be run on a 486-type, personal computer in conjunction with an optical microscope in which the user describes the appearance of a particle in response to a series of questions, or 'prompts', leading to a diagnosis of the particle type. Documentation procedures follow and the results of debris concentration measurements (e.g, Debris Tester) are tabulated and plotted and cross-referenced to the morphological analysis.

Quantitative analysis of particle morphology is undertaken by means of image processing. One such application, known as CAVE (Computer-Aided Vision Engineering) was developed previously to perform quantitative analysis of particle size and shape (7). A neural net procedure has since been added to define a particle's surface features in relation to the associated wear mode (11) and applied to different controlled wear test situations (12).

A Windows version of CAVE has been developed for the analysis of magnetic plug samples. However, there are some unresolved difficulties with its application due to problems with the procedures currently used at EFDC locations to deposit the samples prior to analysis. This has the effect of causing particle overlap and piling up of particles. The quality of incident light illumination of the particles when deposited on opaque substrates is also highly variable. In combination, the two effects result in inconsistent results and further work is required to establish procedures which will permit reliable analysis. This is regarded as being important in relation to the prospects for establishing automatic procedures necessary to speed up morphological analysis and render it a less tedious and subjective activity.

The implementation of these procedures has commenced on a trial basis at EFDC locations responsible for two entirely different types of aircraft: the Tornado, powered by the Rolls Royce RB199 engine, and the Hercules C130, powered by the Allison engine. In the latter, the main requirement is to introduce appropriate procedures for trend monitoring of Debris Tester results linked to periodic particle morphological analysis in which the particles are almost entirely comprised of large, > 100 μm ferrous free metal particles. In the case of the former, the debris is invariably much smaller, < 50 μm in which there is a need to identify particles of different composition with a corresponding requirement to carry out morphological analysis on a more routine basis.

Concluding Remarks: In performing condition monitoring of wearing components using wear debris analysis procedures, the principal requirements are satisfied (ideally) when a fault is detected and correctly diagnosed with no corresponding loss of life, equipment or operational time. However, the other major requirement is to be able to determine the optimum period in which to carry out remedial repairs or replacement of wearing parts. While detection and diagnosis is intended to guarantee that there will be no unforeseen failure, they do not guarantee that repairs, or other interruptions to operation, are not undertaken prematurely. In the absence of any certainty as to when a component will malfunction or cause a deterioration in performance efficiency, a tendency to err on the side of caution is to be expected even if it is known to add considerably to the overall long term cost of the operation.

The procedures now being introduced are necessary to ensure that the present effectiveness of the EFDC operation is maintained and improved in the future against a background of possible reductions in available resources. However, it is recognised that if there was greater confidence in predicting the course of a deteriorating wear situation there would be considerable potential savings without the accompanying increased risk of unscheduled failure. This is most likely to be achieved when there is increased scope for automated analysis procedures coupled to improve co-ordination of condition monitoring data with maintenance histories and operational data.

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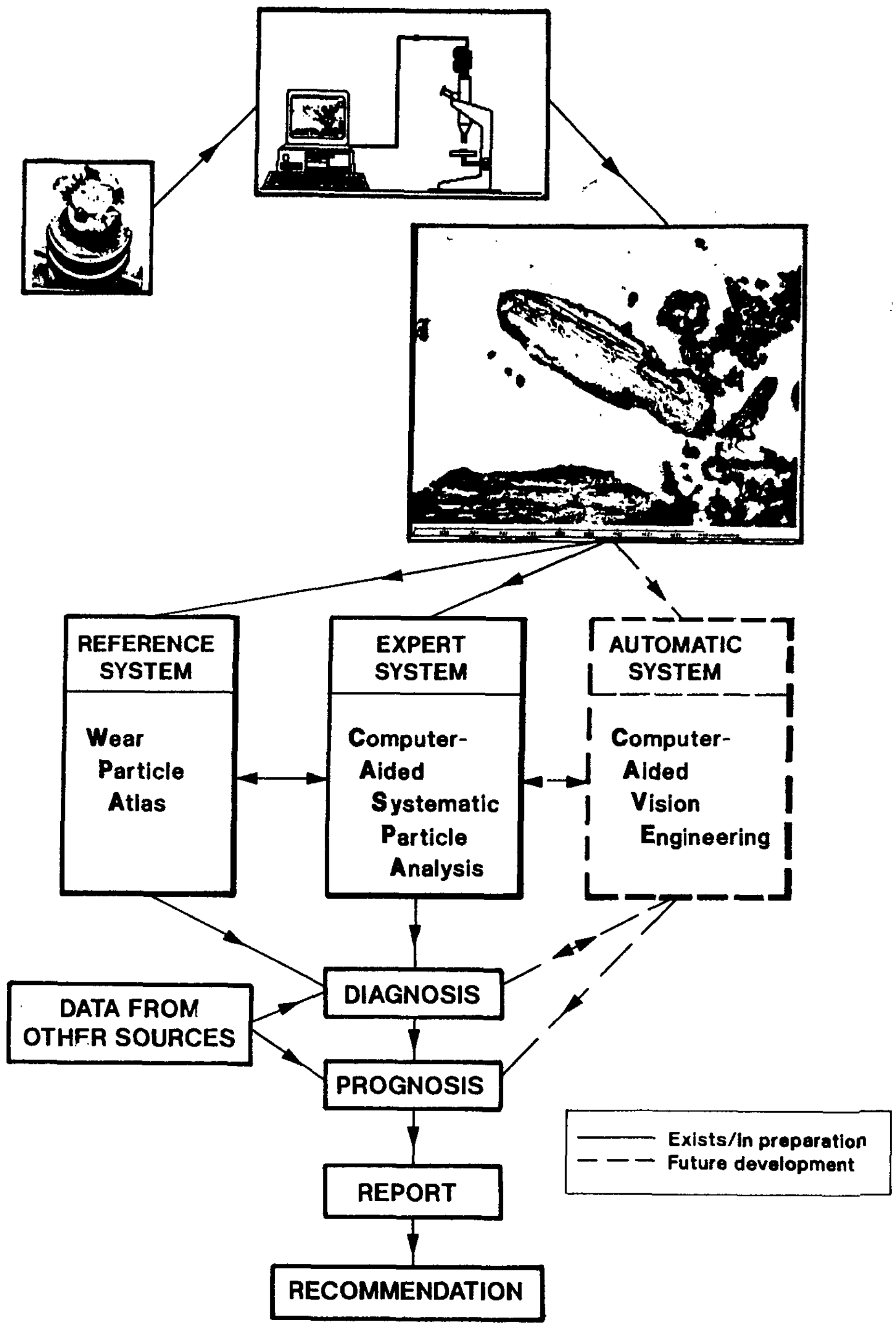
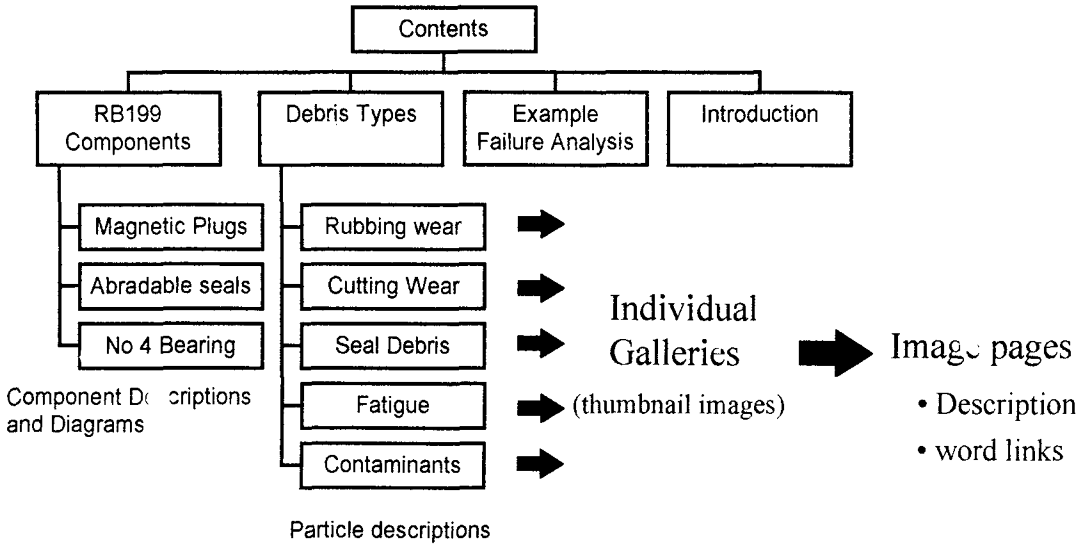


FIGURE 2 PROCESSES INVOLVED IN PERFORMING MORPHOLOGICAL ANALYSIS OF MAGNETIC DRAIN PLUG SAMPLES

RB199 Wear Particle Atlas Structure



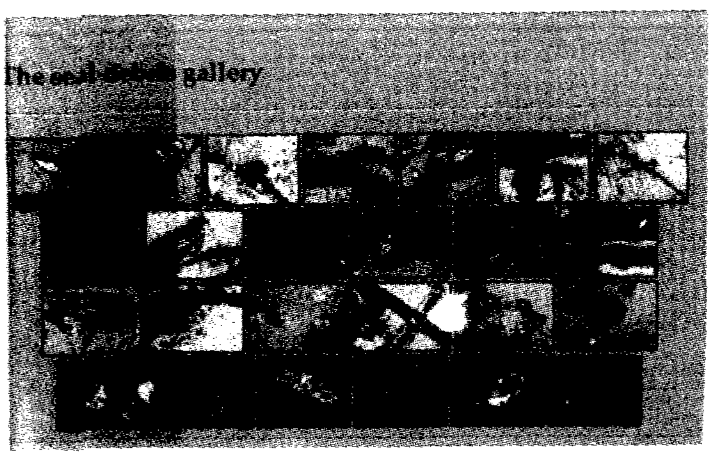


Figure 3 - Sample 'pages' extracted from the Wear Particle Atlas.

Accompanying text including a particle description and word links to other photographs within the Atlas.

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